NON-PROVISIONAL APPLICATION FOR UNITED STATES PATENT

FOR

Annular Cold Plate with Reflexive Channels

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FIELD OF THE INVENTION

[0001] The present invention relates generally to the field of integrated circuits, in particular, probing of integrated circuits.

BACKGROUND OF THE INVENTION

[0002] Optical probes are often employed to probe integrated circuits. Typically, an integrated circuit to be probed is placed in a die plate, which in turn is mated with an annular cold plate to remove heat generated by the integrated circuit during probing.

[0003] As the operating speed of integrated circuits continues to increase, so does the amount of heat generated during probing, and needs to be removed. Experience has shown that the current generation of annular cold plate is unlikely to be able to meet the heat removal requirement of the next generation of high speed integrated circuits.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The present invention will be described by way of exemplary embodiments, but not limitations, illustrated in the accompanying drawings in which like references denote similar elements, and in which:

[0005] **Figure 1** illustrates a simplified side view of an optical probe for probing a die held by a die plate mated with an annular cold plate of one embodiment of the present invention;

[0006] **Figure 2** illustrates a simplified top view of the annular cold plate, the die plate and the die of **Figure 1**;

[0007] **Figure 3** illustrates a simplified exploded view of the annular cold plate, the die plate and the die of **Figure 1**;

[0008] **Figures 4a-4b** illustrate simplified top and bottom exposed views of the coolant fluid channels of the annular cold plate, in accordance with one embodiment;

[0009] **Figures 5a-5c** illustrate alternate relative dispositions of the coolant fluid channels, in accordance with other embodiments;

[0010] **Figure 6** illustrates a simplified cross sectional view of a coolant fluid channel in accordance with one embodiment; and

[0011] **Figures 7a-7b** illustrate alternate surface area enhancement features, in accordance with other embodiments.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0012] Illustrative embodiments of the present invention include, but are not limited to an annular cold plate, and an integrated circuit (IC) probing system having an optical probe and such an annular cold plate.

[0013] Various aspects of the illustrative embodiments will be described using terms commonly employed by those skilled in the art to convey the substance of their work to others skilled in the art. However, it will be apparent to those skilled in the art that the present invention may be practiced with only some of the described aspects. For purposes of explanation, specific numbers, materials, and configurations are set forth in order to provide a thorough understanding of the illustrative embodiments. However, it will be apparent to one skilled in the art that the present invention may be practiced without the specific details. In other instances, well-known features are omitted or simplified in order not to obscure the illustrative embodiments.

[0014] The phrase "in one embodiment" is used repeatedly. The phrase generally does not refer to the same embodiment; however, it may. The terms "comprising", "having" and "including" are synonymous, unless the context dictates otherwise.

[0015] Terms such as "above", "below", "side" and so forth will be used in the description to follow. However, these are relative terms, used for ease of understanding. Whether an element or feature is "above", "beneath" or at the "side" of another element or feature depends on a particular point of view. Thus, the descriptions are not to be read as restrictive on the invention.

[0016] Referring now to **Figures 1-3**, wherein a simplified cross section view of an optical probe for probing a die secured by a die plate mated with an annular cold plate of an embodiment of the present invention, a top view, and an exploded view of the die and annular cold plates without the optical probe, are shown respectively. As illustrated, die **106** is attached to die plate **104**, which in turn is mated with cold plate **102**, resulting in die plate **104** and die **106** being disposed substantially at the center of annular cold plate

102. Together, the assembly, i.e. annular cold plate **102** mated with die plate **104** having die **106**, is positioned "underneath" optical probe **100** allowing die **106** to be probed.

[0017] Die **106** may be interfaced with die plate **104** in any one of a number of techniques. Similarly, die plate **104** may be mated with annular cold plate **102** in any one of a number of techniques.

[0018] Continuing to refer to **Figures 1-3**, optical probe **100** may include one or more light sources capable of selectively producing lights (e.g. laser lights) in various wavelength bands, and a variety of optical arrangements to facilitate focusing the outputted lights onto the die for performing various die probing. Different die plates **104**, each designed for a different silicon product family, may be mated with annular cold plate **102**, allowing different dies of the same or different families to be probed.

[0019] In each case, annular cold plate **102** facilitates cooling for the die being probed, i.e. removal of the heat generated by the die during probing. As will be described in more detail below, in various embodiments, annular cold plate **102** is endowed with various embodiments of a novel coolant fluid channel arrangement, resulting in annular cold plate **102** being more efficient and/or effective as a cooling agent for a die being probed.

[0020] As will be readily apparent from the description to follow, except for the novel coolant fluid channel arrangement, annular cold plate **102** may otherwise be any one of a wide range of such element, assuming any one of a wide range of dimensions, and/or being constituted using any one of a wide range of thermally conductive materials, including but are not limited to copper, aluminum, silver and so forth. Likewise, annular cold plate **102** may be used to facilitate probing of a wide range of dies, e.g. a microprocessor, using a wide range of optical probes.

[0021] Figures 4a-4b illustrate simplified top and bottom exposed views of the novel coolant fluid channel arrangement of the present invention, in accordance with one embodiment. Note that references to the views as top and bottom exposed views are made merely for ease of understanding, as the coolant fluid channels may be exposed with either surface of annular cold plate **102** being considered as the 'top' or 'bottom' surface.

[0022] For the illustrated embodiment, annular cold plate **102** includes two circumfluent coolant fluid channels **402a-402b**. Circumfluent coolant fluid channel **402a** traverses from inlet **404** in a counterclockwise direction to outlet **408**, whereas circumfluent coolant fluid channel **402b** traverses from inlet **404** in a complementary clockwise direction to outlet **408**. The two circumfluent coolant fluid channels **402a-402b** are reflexive, i.e. a later (outlet end) portion of each of the two circumfluent coolant fluid channels **402a-402b** turns on (i.e. a reflection of) an earlier (inlet end) portion. More specifically, for the illustrated embodiment, the two circumfluent coolant fluid channels **402a-402b** cross each other at location **406**, which for the embodiment is approximately at the mid-point of each of the channels, located at the opposite side of inlet **404** and outlet **408**.

[0023] For ease of description, all or part of the portion closer to inlet **404**, before crossing **406**, will be generally referred to as the inlet portion or inlet end of a channel, whereas all or part of the portion closer to outlet **408**, after crossing **406**, will be generally referred to as the outlet portion or outlet end of the channel.

[0024] In various embodiments, during probing, coolant fluid substantially cooler than the ambient environment is provided to channels **402a-402b** through inlet **404**. In various embodiments, the coolant fluid, relative to the heat output of die **106**, is sufficiently cool, such that the coolant fluid remains cooler than the ambient environment when it flows through outlet ends of channels **402a-402b** towards outlet **408**. Accordingly, the configuration allows the outlet end of a channel to insulate the inlet end of the other channel, from the inlet end's "side", making annular cold plate **102** a more efficient/effective cooling arrangement for a die being probed.

[0025] In various embodiments, the coolant fluid, in addition to being sufficiently cool as earlier described, is also sufficiently cool to provide a substantially equal temperature at the circumference of die plate **104**.

[0026] In various embodiments, the coolant fluid is provided at a temperature in the range of – 80°C. and – 140°C. for probing dies with thermal output capacities that raise the temperature of the coolant fluid to no higher than – 5°C. When the coolant fluid exits channels **402a-402b** at outlet **408**. In general, any coolant fluid which temperature, notwithstanding the amount of heat outputted by the die, can be consistently maintained

below the ambient, may be used. An example of a likely suitable coolant fluid is liquid nitrogen . In various embodiments, liquid nitrogen just at the phase change, which temperature is about – 196°C., is used. The liquid nitrogen in a gas state may be combined with refrigerated air at about –90°C., to form a combined gas state at about – 140°C.

[0027] In various embodiments, annular cold plate **102** has a thickness of about 0.5 inches.

[0028] In alternate embodiments, annular cold plate **102** may include more than two circumfluent coolant fluid channels. A pair of channels may cross in another location beside the "mid-point" location of the earlier described embodiment. Further, the inlet and outlet ends of the circumfluent coolant fluid channels may be formed with different materials. In particular, the inlet end of a circumfluent coolant fluid channel may be formed with thermally conductive material, while the outlet end of the circumfluent coolant fluid channel may be formed with a lower thermal conductive material or even a thermal insulator. The circumfluent coolant fluid channels may have individual inlets and/or individual outlets as opposed to the common "splitting" inlet **404** and the common combining outlet **408** of the earlier described embodiment. Annular cold plate **102** may also be thicker or thinner. In other words, in alternate embodiments, many modifications may be made without departing from the self-insulating essence of the coolant fluid channels of the earlier described embodiment.

[0029] **Figures 5a-5b** illustrate two example modifications to the earlier described embodiment. More specifically, **Figures 5a-5b** illustrate a number of alternate relative disposition of the coolant fluid channels, in accordance with a number of alternate embodiments. For the embodiment of **Fig. 5a**, in lieu of the side-by-side relative disposition of the earlier described embodiment, channels **402a-402b** are disposed top and bottom of each other, resulting in the outlet end of a channel being on "top" of the inlet end of another channel, insulating the inlet end from its "top". For the embodiment of **Fig. 5b**, the outlet end of a channel is further split into two portions with one portion disposed on "top" of the inlet end of the other channel, and the other portion disposed "underneath" the inlet end of the other channel, insulating the inlet end from its "bottom"

as well as from its "top". Thus, unlike the earlier described embodiment where the annular cold plate and its coolant fluid channels are co-planar, in these embodiments, the annular cold plate occupies one plane, and the coolant fluid channels occupy another plane, orthogonal to the plane occupied by the annular cold plate.

[0030] **Figure 6** illustrates yet another example modification of the earlier described embodiments. More specifically, **Figure 6** illustrates a cross sectional view of a coolant fluid channel in accordance with an alternate embodiment. For the embodiment, circumfluent coolant fluid channel **402a/402b** is formed by first carving the circumfluent channel from a metal piece. The walls **602** of a carved channel may be lined with a thermally conductive braze-bonding **604**. The lined channel may also be filled with a thermally conductive open cell metallic foam **606** and another metal piece may cap the walls **602** as a roof (or floor) **608** through another braze bonding **610**. Each of the metal pieces, brazed bonding **604/610**, metal foam **606** (a form of surface area enhancement) and roof/floor **608** may be made of thermally conductive materials such as, but not limited to, copper, aluminum, silver, and so forth. However, in alternate embodiments, bonding **604/610** may be accomplished with another process. Further, in alternate embodiments, the wall **602** may be "hybrid" with the inlet region of wall **602** being made of thermally conductive material, while the outlet region is made of thermal insulator. The thermally non-conductive portion may be secured using adhesives, e.g. silicone or epoxy.

[0031] **Figures 7a-7b** illustrate yet two other example modifications to the earlier described embodiments. More specifically, **Figures 7a-7b** illustrate perspective views of two example surface area enhancement configurations, which may be used in lieu of the earlier described metallic foam filling, in accordance with two alternate embodiments. Surface area enhancement configuration **702** of **Figure 7a** includes a number of surface area enhancing fins **704**, whereas surface area enhancement configuration **706** of **Figure 7b** includes a number of surface area enhancing pins **708**. The number and dimensions of the surface area enhancing fins or pins may be tailored to meet a particular application, that is the input temperature of the coolant fluid, the amount of heat produced by a

particular die that needs to be dissipated during probing, and so forth. Similarly, the surface area enhancements materials may be secured to channel **402a/402b** with thermal conductive adhesives.

[0032] Thus, a novel annular cold plate and its application have been described. Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent implementations may be substituted for the specific embodiments shown and described, without departing from the scope of the present invention. This application is intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.